THE REPEATABILITY AND REPRODUCIBILITY OF PROPOSED TEST PROCEDURES AND INJURY CRITERIA FOR ASSESSING NECK INJURIES IN REAR IMPACT

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Paper number 05-0340

ABSTRACT

The European Automobile Manufacturers Association (ACEA) has carried out a study looking at the repeatability and reproducibility of the proposed test procedures and injury criteria. For repeatability, 3 repeat tests were carried out on 3 different seats using a 16 km/h delta-V test pulse. To evaluate reproducibility, the same 3 seats were tested to a common protocol at 5 different test labs using two different test pulses (16 and 25 km/h delta-V). The sleds used included both acceleration and deceleration types. A wide range of acceleration, simple force/moment and combined force and moment injury criteria were evaluated.
In general, repeatability of the sled pulses was reasonable but significant variations in pulses and test set up were found between laboratories. As a result, more precise procedures, test pulse corridors and an agreed definition of T_{zero} (beginning of impact) are needed.
Repeatability of most of the injury criteria at 16 km/h was acceptable but reproducibility was poor, with variations of up to 40% for some of the criteria. The situation was even worse at 25 km/h, with some criteria showing variations of over 100%. Great care therefore needs to be exercised in selecting appropriate injury criteria, in selecting the stringency of assessment limits and in comparing results from different laboratories. The variation in results also questions the use of high severity pulses for neck injury assessment.

INTRODUCTION

A number of organisations are carrying out or planning sled tests on car seats to assess the risk of soft tissue neck injuries and to make comparisons between vehicles. Most of these tests will use a recently developed dummy (BioRID) but a number of different test pulses and injury criteria have been proposed. There is little experience available in the use of these test procedures and limited knowledge of their repeatability and reproducibility. Nevertheless, data are widely exchanged for comparisons, without checking if the test protocols followed exactly the same data processing definitions.
The European Automobile Manufacturers Association (ACEA) has carried out a study looking at the repeatability and reproducibility of the proposed test procedures and injury criteria. This study helped in identifying the different problems which may be encountered if a test protocol is not sufficiently detailed enough. It aimed at highlighting the possible improvements to reduce dispersion and the test configurations or criteria that should not be used to assess whiplash because of non reproducibility.

PRESENTATION OF THE STUDY

In order to determine reliability of current whiplash assessment, a whiplash testing programme has been defined. The purpose is :

- to assess the feasibility and reproducibility of the contemplated test procedure and test tools
- to find the key test parameters/ conditions which would ensure that the test are reproducible/repeatable
- to prepare recommendations for the exploitation of test measurements/ results and for the ways and means to obtain them
- to record unexpected problems/risks of problems with the contemplated test procedure and tools

Description of the test matrix

The defined test matrix is made of 36 tests :

- two different pulses that are thought to be used to assess whiplash and seat stability by EuroNCAP

- three different seat models with different levels of performance in published ratings

- the same model will be tested three times in one laboratory to assess repeatability

- five different laboratories with different tests set-ups and tools to carry out the tests to assess reproducibility

The tests have been carried out according to the test procedure which is currently studied within Euro-NCAP whiplash working group (whiplash test procedures such as Thatcham and IIWPG [1], ADAC [2], SNRA [3]). Therefore, the key test conditions which should be monitored by test laboratories (the dummy and dummy installation, the pulses, the seat adjustments) are described in the following paragraphs.

Seat adjustment

Seats were rigidly mounted on sled with actual rail angle and standard heel point values. Care was taken to reproduce similar configuration in all the labs for each seat model.

Seats were set in mid position and mid height as usually required in whiplash test procedures. Head Restraints (HR) were set according to the RCAR procedure [4] : mid locking position when Z-lock available or else fully down.

Dummy adjustment

The Head Restraint Measuring Device (HRMD) defined by RCAR together with an SAE J826 H-point machine was used to define H-point and backset (horizontal distance between head and HR). Backset used to control the BioRID head position was measured with HR in its fully up position in order to have easy and reproducible data to record in all the labs in whiplash test procedures. The BioRID dummy was installed in the seat by controlling the parameters presented in table 1.

Table 1.
Control parameters to install BioRID dummy in the seat.

Location	Target Measurements	Tolerance
X Dummy H-Point	Seat H point + 20mm (Forward)	± 10mm
Z Dummy H-Point	Seat H point + 6mm (Lower)	± 10mm
Pelvis angle	26,5°	± 2,5°
Head plane	0° (Level)	± 1°
Dummy backset	HRMD backset + 15mm (Forward)	± 5mm

In order to prevent the dummy from jumping out of the seat during rebound, a 2 point seat belt was used to restrain the dummy during rebound phase. It was loose with same amount of slack for all the seats and in all the labs, so that the lap belt could not interfere on the behaviour of the dummy during the rear impact.

Test pulses and type of sled

The IIWPG pulses have been used : deltaV = 16 km/h and 25 km/h. They are presented in chapter “sled pulses”, later in this paper.

Different sled facilities have been used :

- TNO and Fiat used an hydraulic acceleration sled,

- Thatcham used a pneumatic acceleration sled

- ADAC used a deceleration sled with hydraulic brake as stopping device

- Faurecia used a pendulum device for the 16 km/h tests and a deceleration sled with hydraulic brake as stopping device for the 25 km/h tests

Parameters analysed and definition

The first definition needed to analyse the data is the definition of T_{zero} (beginning of impact). T_{zero} is defined as the first point above 0.5 g on the sled X-accel channel filtered at CFC 60. Change of velocity (or “deltaV”) is calculated from the sled X-channel filtered at CFC 180.

All the criteria that could be measured or calculated for whiplash studies have been used :

- accelerations of BioRID head, spine and pelvis

- force and moment on BioRID upper and lower neck

- combined criteria such as NIC, Nkm and LNL

- contact between BioRID head and HR

- …

An example of the method of assessment for repeatability and reproducibility is presented below. For a given parameter, X, measured during the 16 km/h tests for all the same seat model, seven values will have to be compared (one for each test). They are presented in Equation 1.

$$\begin{cases} \text{Thatcham} = X_{Ta}, X_{Tb} \text{ and } X_{Tc} \\ \text{ADAC} = X_{A} \\ \text{Faurecia} = X_{F} \\ \text{TNO} = X_{T1} \\ \text{Fiat} = X_{F1} \end{cases} \quad (1).$$

The following definitions are used to assess repeatability (see Equations 2 to 6).

$$X_{Tmean} = \frac{(X_{Ta} + X_{Tb} + X_{Tc})}{3} \quad (2).$$

$$\text{Max}_3 = \text{MAX}(X_{Ta}\,; X_{Tb}\,; X_{Tc}) \quad (3).$$

$$\text{Min}_3 = \text{MIN}(X_{Ta}\,; X_{Tb}\,; X_{Tc}) \quad (4).$$

$$\text{Dispersion} = \Delta_3 = \text{Max}_3 - \text{Min}_3 \quad (5).$$

$$\text{Scattering} = \frac{\text{Max}_3 - \text{Min}_3}{X_{\text{Tmean}}} \text{ x } 100\,\% \qquad (6).$$

The following definitions are used to assess reproducibility (see Equations 7 to 11).

$$X_{\text{mean}} = \frac{(X_{\text{Tmean}} + X_A + X_F + X_{T1} + X_{F1})}{5} \quad (7).$$

$$\text{Max}_5 = \text{MAX}(X_{\text{Tmean}}; X_A; X_F; X_{T1}; X_{F1}) \quad (8).$$

$$\text{Min}_5 = \text{MIN}(X_{\text{Tmean}}; X_A; X_F; X_{T1}; X_{F1}) \quad (9).$$

$$\text{Dispersion} = \Delta_5 = \text{Max}_5 - \text{Min}_5 \qquad (10).$$

$$\text{Scattering} = \frac{\text{Max}_5 - \text{Min}_5}{X_{\text{mean}}} \text{ x } 100\,\% \qquad (11).$$

ANALYSIS OF RESULTS

Initial set-up

The assessment of the initial position for the seat and for the dummy is made using the HRMD + SAE J826 H-point machine (also called Oscar + HRMD). Measurements recorded were :

- stem angle of HR with respect to vertical
- torso angle
- H-point
- backset and height (measured with different position of HR)

BioRID data are also used :

- H-point
- backset and height (measured with HR in its fully up position and with HR in its tested position)
- pelvis angle

The following paragraphs present the analysis of some of these parameters linked to the initial set-up.

Torso angle

The set-up procedure requires a torso angle of 25 +/- 1°. This requirement was fulfilled, but the whole band of tolerance, as proposed in the protocol, was needed to achieve it. None of the lab shows any particularity with respect to the others, such as seat set-up always in the extreme part of the band of tolerance for all the seats and seat models. Figure 1 shows that the set up of the seat can lead to torso angle variations of up to 1.6° depending on where the test was carried out. This is due to the fact that seat back recliner could be a step adjustment, not a continuous one. Even on a seat with continuous adjustment, it could take a long time to set-up the seat at exactly 25°.

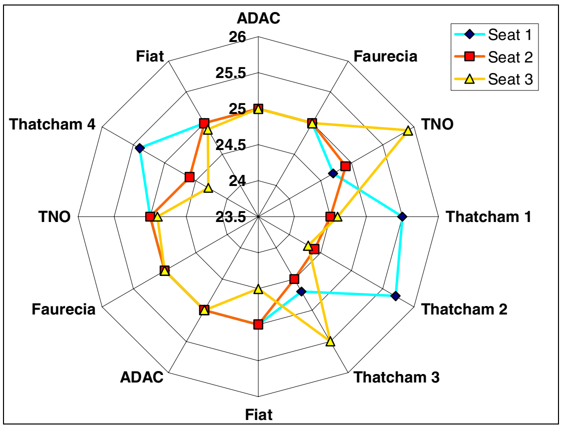

Figure 1. Torso angle dispersion.

Oscar + HRMD H-point

For H-point coordinates, the reference point is the seat back articulation. In the following graphs (figure 2 to 5), white crosses represent repeatability results. Maximum dispersion is represented by a coloured dotted rectangle for each seat model. Mean value is also given thanks to a different coloured symbol.

The combination of X and Z H-point measured on Oscar + HRMD and their dispersion is shown in figure 2 with an extensive analysis of the results. We can notice that none of the lab shows any particularity with respect to the others. Dispersion appears in the H-point X and Z coordinates for all the seat models (up to almost 20 mm in X and up to 22 mm in Z).

We can also notice that repeatability (white crosses) is better than reproducibility for X and Z H-point except for Seat 1 in Z. Up to twenty millimetres of dispersion occurred in X and Z for H point location. This dispersion is present for the 3 seat models for X H-point location.

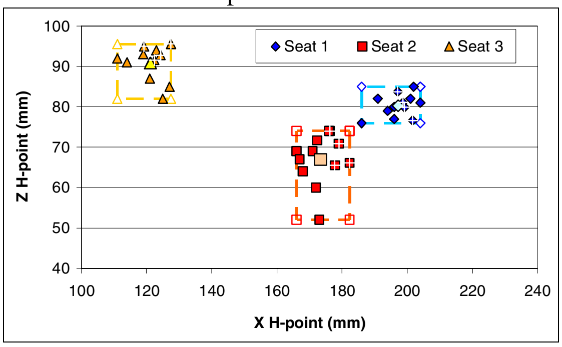

Figure 2. H-point distance measured on Oscar+HRMD.

Head to HR distance measured with HRMD

Backset and height are combined in figure 3. The commonly used HRMD rating zones are also presented: The green line is the border between "good" and "acceptable" rating zones, the yellow line is the border between "acceptable" and "marginal" rating zones and the orange line is the border between "marginal" and "poor" rating zones according to RCAR geometrical rating procedure [4].

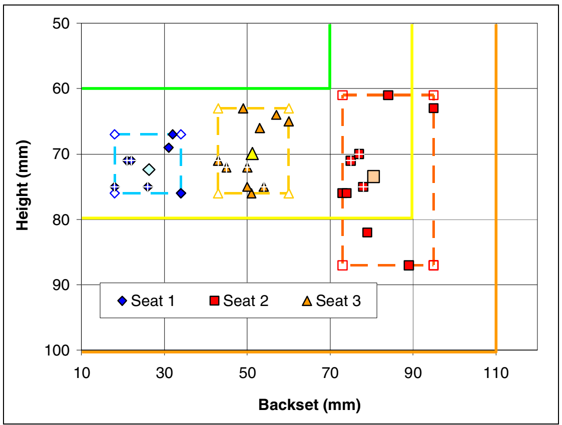

Figure 3. Head to HR distance measured on HRMD

We can see that each seat model has a different backset average (from 26 mm for Seat 1 to 80 mm for Seat 2) and a height average (from 69.9 mm for Seat 3 to 73.4 mm for Seat 2). This is due to the fact that each seat has its own structure design and its own HR volume. We can also add that none of the lab presents a specific trend, such as smaller backset than the ones measured in the other labs. Maximum dispersion for backset is 22 mm and maximum dispersion for height is 26 mm.

Since dispersion can be above 20 mm for each direction, this means that theoretically, the geometrical rating for the same seat can go from "Good" (green) to "Marginal" (orange).
If we suppose training to install HRMD can be improved, we can focus on Thatcham points (repeatability). In this case, dispersion is lowered since backset gets maximum dispersion of 11 mm and height gets maximum dispersion of 5 mm).

BioRID H-point

The combination of X and Z H-point measured on BioRID and their dispersion is shown in figure 4. Dispersion appears in the H-point X and Z coordinates for all the seat models but not to the same amount (up to 28 mm in X and up to 33 mm in Z). None of the lab can be distinguished from the others with respect to the use of the band of tolerance.
We can notice that repeatability (white crosses) is better than reproducibility for X and Z H-point.

Maximum dispersion in reproducibility assessment is about 30 mm in X and Z for BioRID H-point location.

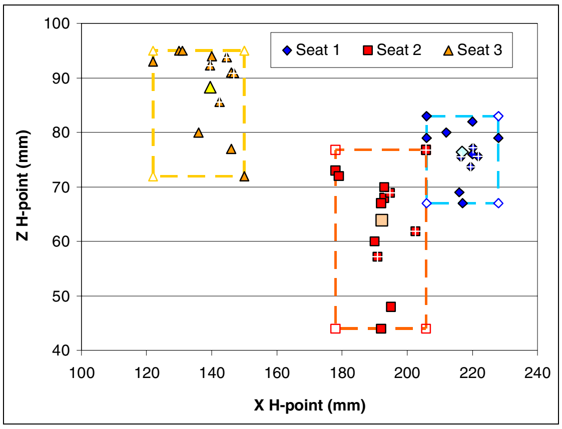

Figure 4. H-point distance measured on BioRID.

Head to HR distance measured with BioRID

Backset and height are combined in figure 5.

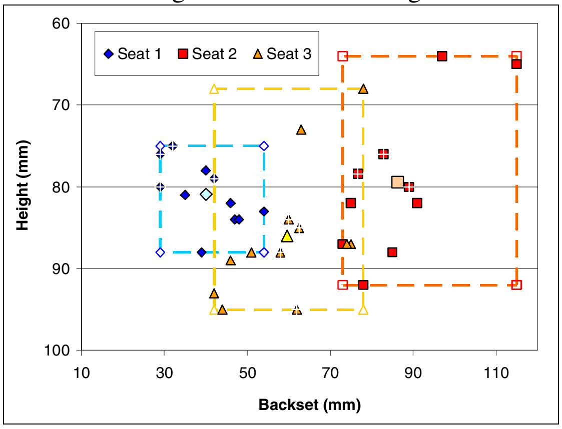

Figure 5. Head to HR distance measured on BioRID.

Each seat model has more dispersion for BioRID than for HRMD backset. Backset average ranges from 40 mm for Seat 1 to 86 mm for Seat 2. We can see that there is not so much difference for height since height average ranges from 79 mm for Seat 2 to 86 mm for Seat 3.
Moreover, maximum dispersion for BioRID backset is 42 mm and maximum dispersion for height is 28 mm.
It is also important to notice that in the current test procedures, there are different ways to measure backset for BioRID. In our opinion, it is important to distinguish the purpose of the measurement. One measure is used to ensure the head to be placed 15 mm forward from the HRMD head. This measure can be done with any reference point (seat, sled or even north pole thanks to GPS) and has no need to be linked to the actual HR position. But this measure is not useful for engineers. What is interesting for engineering purposes is the actual distance between BioRID's head and HR. For this, a specific method of measurement has to be defined. This should be discussed within BioRID Users Meeting.

Dummy final set-up : H-point

In order to check whether BioRID has been correctly installed with respect to HRMD, we can analyse the difference in H-point coordinates between the two machines. For reminder, BioRID X H-point should be 20 mm forward of HRMD one, and Z H-point should be 6 mm downward as already specified in table 1.

Figure 6 shows X delta H-point for all the tests carried out (16 and 25 km/h). X H-point shift seems to be easy to achieve. The average shift ranges from 18.3 mm for seat 3 to 19.69 mm for seat 1. But the large band of tolerance proposed in the test protocol is used by the different labs since maximum dispersion goes up to 15 mm.

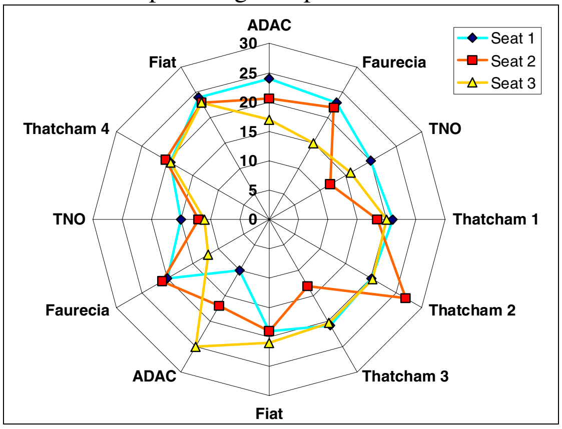

Figure 6. Difference of H-point in X between BioRID and Oscar + HRMD.

Figure 7 shows Z delta H-point for all the tests carried out. For this parameter, all the seat models can be compared since they should all reach the same target.

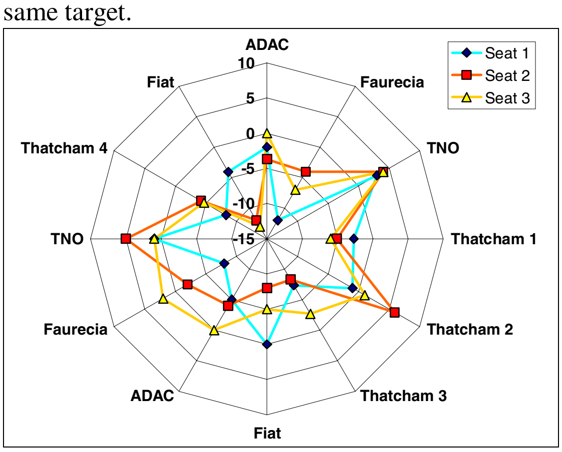

Figure 7. Difference of H-point in Z between BioRID and Oscar + HRMD.

Z H-point shift seems to be less easy to achieve than X one. The theoretical shift should be –6 mm but average shift between -2.53 mm for seat 3 and -3.87 mm for seat 1. Here again the large band of tolerance proposed in the test protocol is used by the different labs since maximum dispersion is 18 mm.

Figure 8 presents the same results in a 2-D format. White crosses represent repeatability results. Maximum dispersion is represented by a coloured dotted rectangle for each seat model. Mean value is also given thanks to a different coloured symbol. A fourth set of information has been added to this graph (green dotted rectangle + green circle point). It represents the official target for BioRID H-point with respect to HRMD.

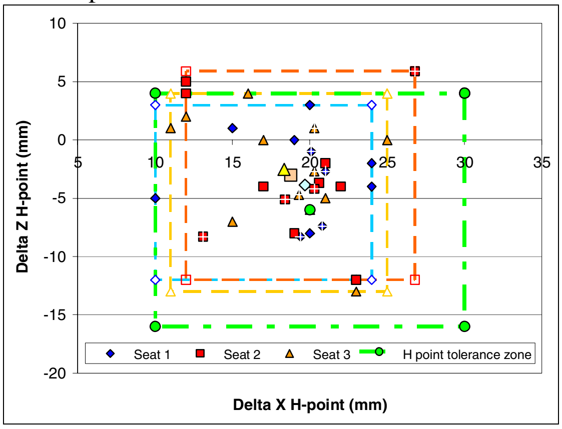

Figure 8. Difference of H-point in X and Z between BioRID and Oscar + HRMD – comparison with BioRID official H-point tolerance.

For the three seat models, average points are really close together. White crosses highlight the repeatability points, and we can notice they are closer together than reproducibility points. Training would help improving BioRID installation. But even with repeatability points, it can be noticed that Z H-point target should be modified, since the majority of points are above the theoretical target. Therefore, it should be recommended to modify Z H-point target for BioRID. Our proposal would be to require BioRID H-point to be at the same height than Oscar + HRMD one.

Dummy final set-up : distance between head and HR

Figure 9 shows difference in backset and height between BioRID and HRMD for all the tests carried out.

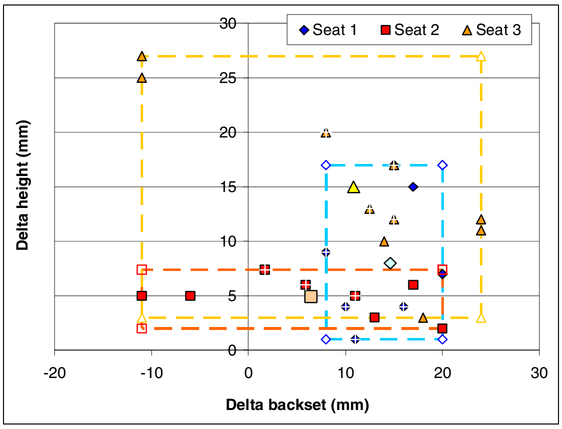

Figure 9. Difference of head to HR distance in X and Z between BioRID and Oscar + HRMD.

Backset shift seems not to be so easy to achieve. Theoretical shift is 15 mm (with HR in its fully up position), and BioRID positioning fulfilled this requirement. But when backset was measured with HR in its tested position, the average shift ranges from 6.45 mm for seat 2 to 14.63 mm for seat 1. The large band of tolerance is, here again, fully used since maximum dispersion is 35 mm between the two extreme positions.
Height shift between Oscar + HRMD and BioRID seems to be dispersive and linked to the seat model. The average shift ranges from 4.93 mm for seat 2 to 15 mm for seat 3. This means that HRMD is always lower than BioRID. Here again the large band of tolerance is fully used since maximum dispersion is 24 mm. Measurement method for backset and height between BioRID and HRMD has to be improved if we want to get good reproducibility.
A clear method for measuring backset has to be defined. It should take into account the possible different geometries a HR could have.

Sled pulse

The comparison of the pulses carried out in the different test lab is made in the following sections. They are compared with the target pulse (defined by IIWPG) for both 16 and 25 km/h severity, and with the corridor already defined by IIWPG for 16 km/h.
All the pulses are analysed thanks to the T_{zero} definition which was described in chapter "Parameters analysed and definition".

DeltaV = 16 km/h

Seven pulses can be compared for the 16 km/h test severity, for each seat model. Figure 10 presents this comparison for seat 2.

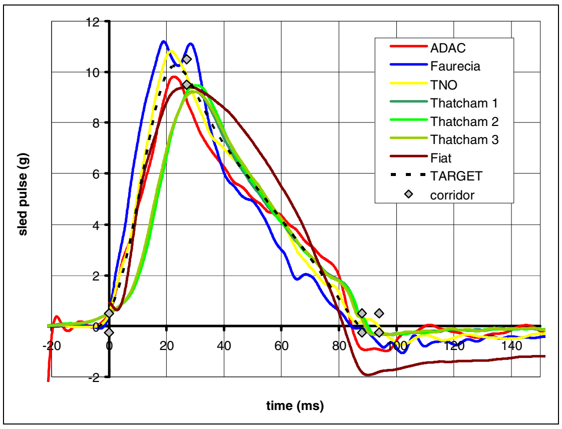

Figure 10. Comparison of sled pulses for the different 16 km/h tests carried out on seat 2.

Results were similar for seat 1 and seat 3. We can notice that the peak is between 9.2 g and 11.2 g. None of the sleds fulfil~~s~~ the corridor requirements. The shift in time can be explained because of the T_{zero} definition used here which is different from the one currently used by IIWPG *(IIWPG T_{zero} is such that peak pulse occurs at 27 ms)*, but there is not such an explanation for the magnitude of the sled pulse.
Moreover, it is difficult to distinguish between the curves whether the sled is a deceleration one or an acceleration one. The only comment we can make is that T_{zero} definition as proposed by IIWPG would be difficult to apply to the Faurecia pulse (double peak pulse).
The resultant change of velocity for seat 2 is presented in figure 11. The change of velocity is calculated from T_{zero} up to the time when sled acceleration goes below 0.5 g.

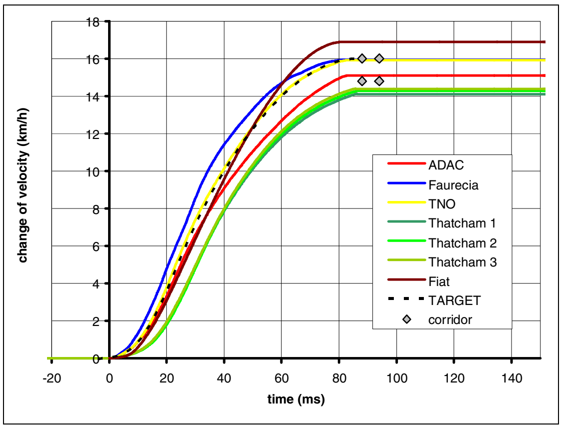

Figure 11. Comparison of sled pulses for the different 16 km/h tests carried out on seat 2.

Results were similar for seat 1 and seat 3. We can notice that this change of velocity is between 14 and 17 km/h.
It is acknowledged that there is a need to better define the pulse characteristics. The data presented here is being used by groups such as Euro NCAP to define the pulse more precisely, probably using a combination of requirements for acceleration levels and deltaV.
Moreover, after the ACEA tests had been performed, Thatcham subsequently improved their pulse performance and meet now the corridor.

DeltaV = 25 km/h

Five pulses can be compared for the 25 km/h test severity, for each seat model. Figure 12 presents this comparison for seat 3.

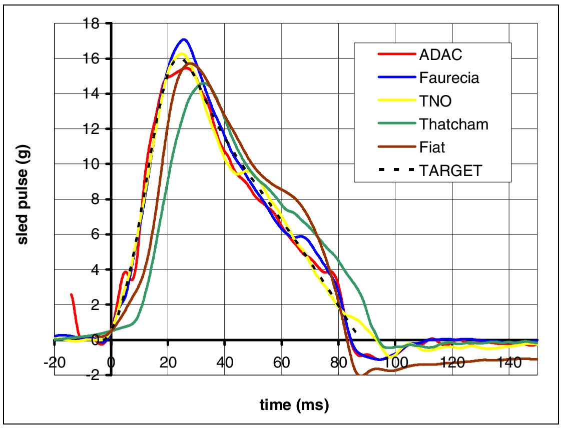

Figure 12. Comparison of sled pulses for the different 25 km/h tests carried out on seat 3.

Results were similar for seat 1 and seat 2. We can notice that for this severity, the peak is between 14.7 g and 17 g.

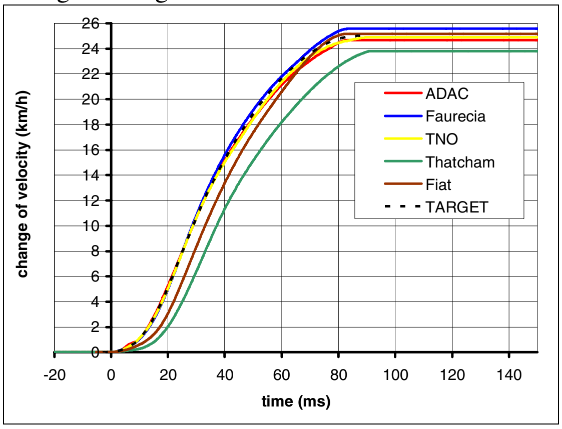

Figure 13. Comparison of sled pulses for the different 25 km/h tests carried out on seat 3.

The change of velocity up to the time when sled acceleration goes below 0.5 g is between 23.8 and 25.6 km/h.

<u>Conclusion on sled pulse</u>

We can conclude that significant variation in pulse and set up have been documented. But repeatability of sled pulses is acceptable. Future work should be devoted to define more accurate requirements on sled pulse and change of velocity. The first action would be to define a corridor for the 25 km/h (impact severity dedicated to seat stability only). Moreover, general accepted definition of T_{zero} is needed since 3 different definitions are currently proposed.

Finally, there is no clear influence of sled type on pulse characteristics and on initial position.

Influence of the different set-ups and sled pulses on dummy readings

Dummy readings have been compared for repeatability and reproducibility tests in order to assess the dispersion that could be due to difference in dummy set-up, sled pulse and type of sled. For this purpose, minimum, maximum and average values are presented for the main criteria studied in the different current ratings (see figure 14 to 25). In order to assess the consequences of dispersion with respect to a final rating, it has been decided to use thresholds (upper and lower thresholds) for each criterion.

In the following figures, the thresholds are represented as follows:

- upper level of rating -----
- lower level of rating -----

It is important to note that the thresholds used in this study are **<u>NOT</u>** proposed by ACEA but are mainly the ones currently used or proposed in published whiplash ratings (Thatcham and IIWPG, SRA, ADAC). They are presented in table 2.

Table 2.
High and low performance level for assessing influence of rating on dispersion at different impact severities.

	High performance	Low performance
HRMD data		
Backset (mm)	70	90
Height (mm)	60	80
BioRID data		
Fx+ upper (N)	130	400
Fz+ upper (N)	700	1400
NIC	10	20
Nkm max	0.3	0.5
LNL	1.5	3.0
T1 (g)	9	15
THRC	70	120
TrelHRC	43	93

In this chapter, the type of graph used is as follow : 3 x 3 bars representing the 3 seat models in the 3 type of tests (repeatability at 16 km/h, reproducibility at 16km/h and reproducibility at 25 km/h). For each bar, the dark blue part shows the minimum value recorded for the criteria under study (Min_3 for repeatability and Min_5 for reproducibility), the light blue shows the maximum one (Max_3 for repeatability and Max_5 for reproducibility)and the yellow symbol shows the mean value(X_{Tmean} for repeatability and X_{mean} for reproducibility).

<u>T1 acceleration</u>

Maximum value of T1 acceleration in X CFC 180 up to the end of contact between head and HR as defined in [6] is studied in this section.

Figure 14 presents the results for T1 acceleration.

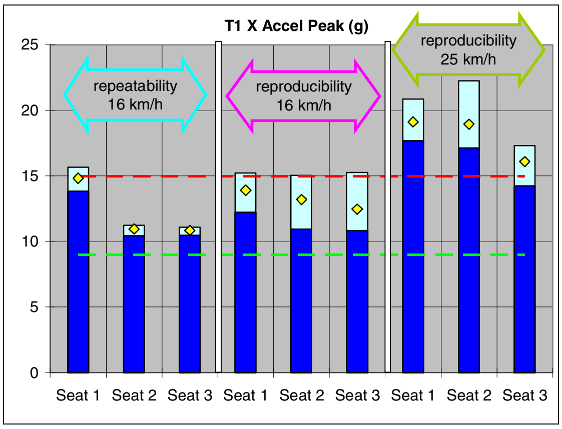

Figure 14. Comparison of dispersion analysed on T1 acceleration.

Repeatability is far much better than reproducibility for this parameter. Dispersion at 16 km/h is almost as large as the band of tolerance. This means that a seat could be rated green in one test and red in the other.

In order to decrease dispersion, a different CFC filter can be used, or 3ms duration values.

The three seats show approximately the same trend in reproducibility tests. Whereas seat 1 shows a different trend in repeatability tests than the two other ones.

NIC

Figure 15 presents the results for NIC.

NIC is calculated from Head accel and T1 accel in X filtered at CFC 180. Maximum value is taken up to the end of contact between head and HR as defined in [6].

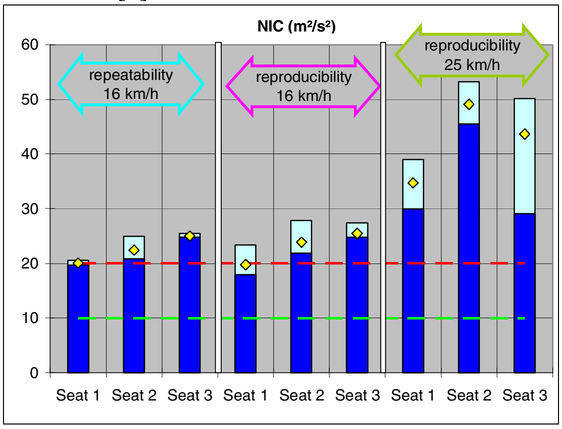

Figure 15. Comparison of dispersion analysed on NIC.

Here again, dispersion is less important in repeatability than in reproducibility tests. But it is large enough to be above or below the red line.

Data at 25 km/h shows the very large dispersion of this parameter for all the seat models.

THRC : 1st time of contact between head and HR

Figure 16 presents the results for THRC (absolute values).

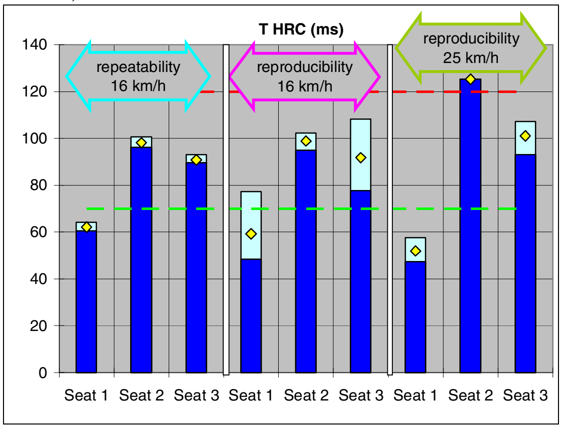

Figure 16. Comparison of dispersion analysed on THRC.

This figure shows the raw data which could be seen as strongly dependent on T_{zero} definition. Here again, repeatability is good, but reproducibility is not.

It should be noted that only 1 result was reliable for seat 2 at 25 km/h.

In order to remove the influence of T_{zero} definition and of the first ms of the sled acceleration, it has been proposed to determine a relative time of HR contact. In theory, if this time is taken with respect to peak sled pulse, T_{zero} definition will have no more influence. This is why we have computed a 2nd THRC, a relative one, TrelHRC. The thresholds have been computed by subtracting 27 ms from the threshold proposed for THRC. Therefore we have an assessment of dispersion for head to HR contact time with no influence of T_{zero} definition.

Figure 17 presents the results for TrelHRC (relative values).

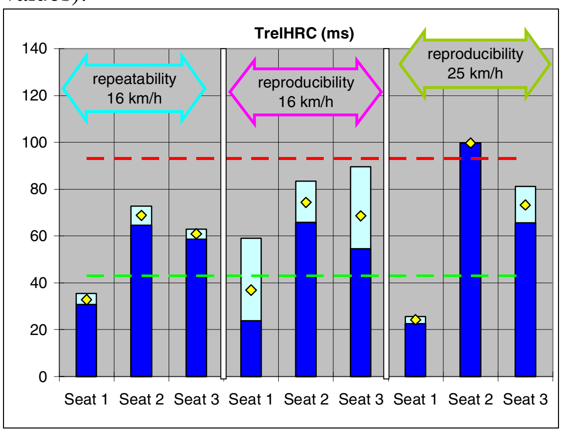

Figure 17. Comparison of dispersion analysed on TrelHRC.

Unfortunately dispersion has not been improved thanks to this solution. Therefore, it is not possible to say that difference in THRC is only due to difference in T_{zero} definition. This is an intrinsic dispersion, because of difference in seat set-up that may generate a difference in backset between the different seats from the same model and because of measurement dispersion.

Fx : Shear force – upper neck

Figure 18 presents the results for Fx, upper neck shear (positive value only).

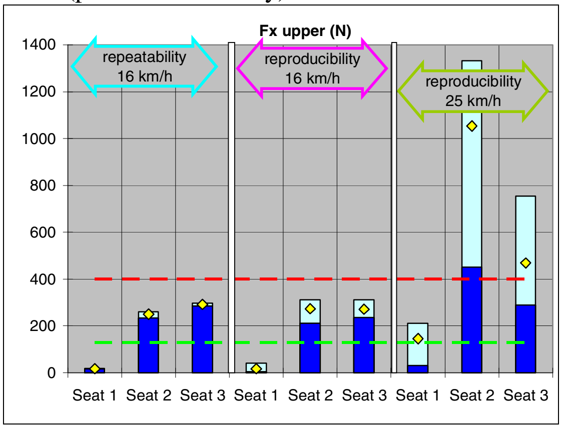

Figure 18. Comparison of dispersion analysed on Fx upper neck.

Positive shear force measured on the upper neck shows very good repeatability results, and slightly worse reproducibility results at 16 km/h but reproducibility at 25 km/h is not acceptable at all.

Fz : Tension force – upper neck

Figure 19 presents the results for Fz, upper neck tension.

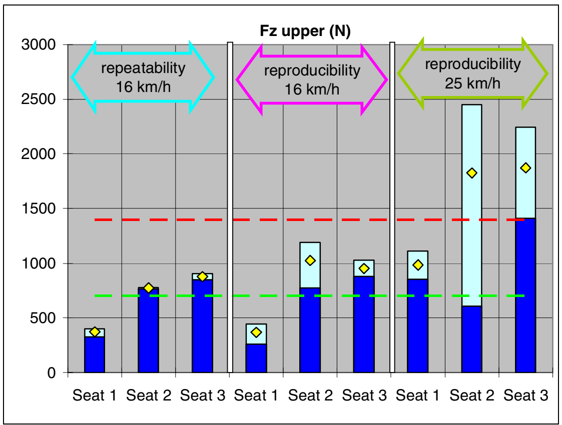

Figure 19. Comparison of dispersion analysed on Fz upper neck.

Tension force measured on the upper neck also shows very good repeatability results, moderate reproducibility results at 16 km/h. But reproducibility at 25 km/h is not acceptable at all.

Nkm and its 4 components

Figure 20 to 24 present the results for Nkm and its 4 different components.

If we first analyse the 2 components made with flexion (My > 0), i.e Nfa and Nfp (figures 20 and 21), we can see repeatability is very good and reproducibility at 16 km/h is acceptable. But reproducibility at 25 km/h is unacceptable.

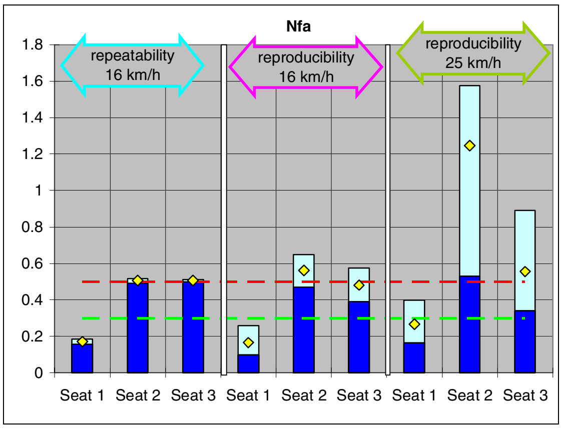

Figure 20. Comparison of dispersion analysed on Nfa.

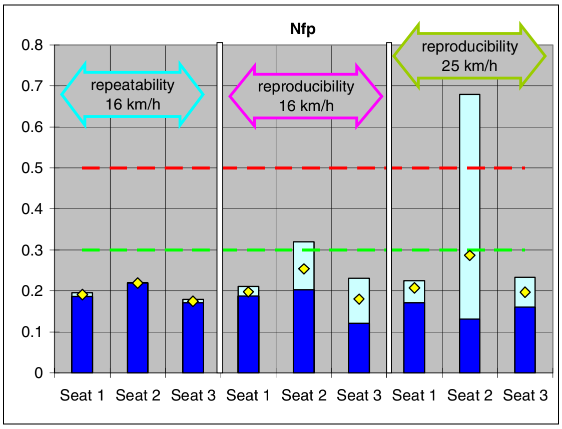

Figure 21. Comparison of dispersion analysed on Nfp.

We can also notice that Nfa is higher than Nfp for all impact severities. Nfa is generally close to the red limit whereas Nfp is close to the green one.

Then, if we analyse the 2 components made with extension (My < 0), i.e Nea and Nep (figures 22 and 23), we can see repeatability is very good and reproducibility at 16 km/h is acceptable. But reproducibility at 25 km/h is unacceptable.

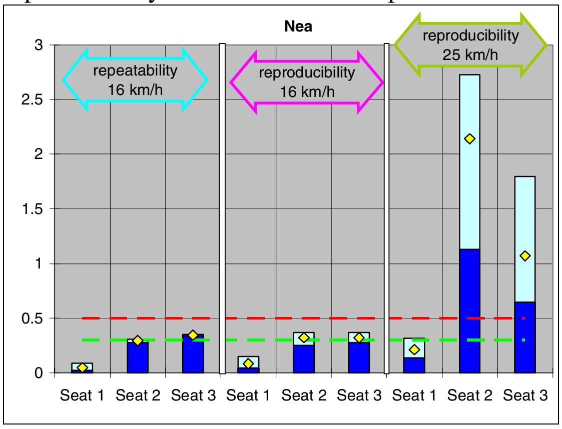

Figure 22. Comparison of dispersion analysed on Nea.

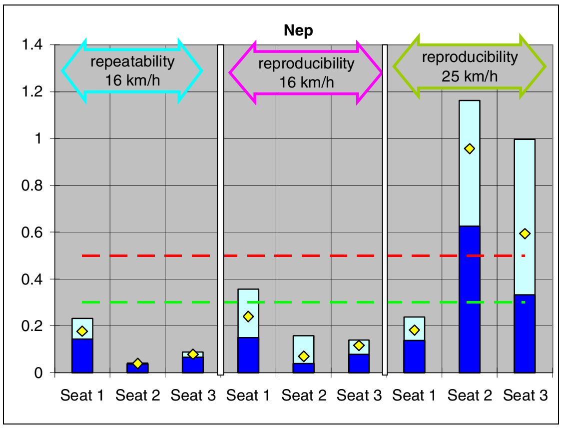

Figure 23. Comparison of dispersion analysed on Nep.

We can also notice that Nea is higher than Nep for all impact severity. For 16 km/h tests, Nea is generally above the green limit whereas Nep is below.

By taking into account all the 4 components of Nkm, we can create a graph with Nkm max values (see figure 24).

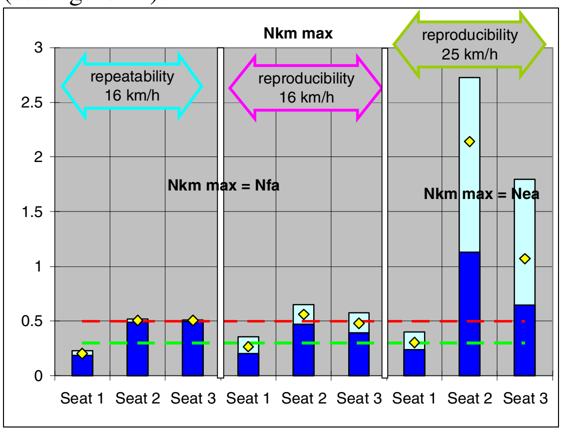

Figure 24. Comparison of dispersion analysed on Nkm max.

For the 16 km/h tests, maximum values are made by Nfa. But it is the Nea component that gives the maximum magnitude for 25 km/h tests. This is the reason why it is not recommended to compare Nkm results without separating the components.

<u>LNL : lower neck load index</u>

Figure 25 presents the results for LNL index (a combination of shear, tension and extension lower neck loads as defined in [6]).

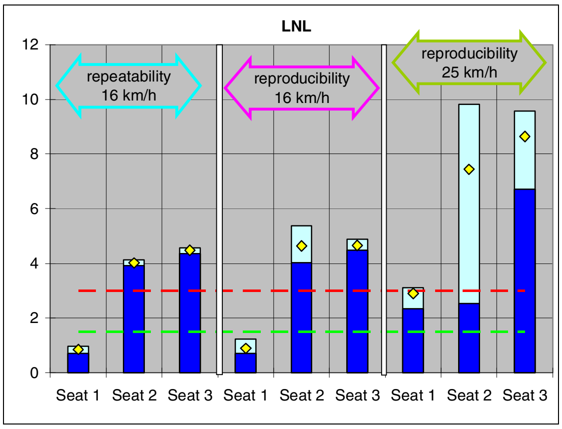

Figure 25. Comparison of dispersion analysed on LNL.

Here again, we can see repeatability is very good and reproducibility at 16 km/h is acceptable. But reproducibility at 25 km/h is unacceptable for two of the seat models.

DISCUSSION

Maximum scattering with respect to test severity

In order to quantify dispersion, the 3 following figures present the scattering, as defined in equations (6) and (11) of several parameters analysed in this study (backset, height, and biomechanical parameters) and for each seat model. There is one graph per type of analysis (repeatability, reproducibility 16 km/h and reproducibility 25 km/h).

<u>Maximum scattering for repeatability assessment at 16 km/h</u>

Repeatability at 16 km/h (see figure 26) shows that scattering is acceptable (around 20%) for all the parameters except for Nkm (mainly Nea and Nep which reached more than 50% of dispersion).

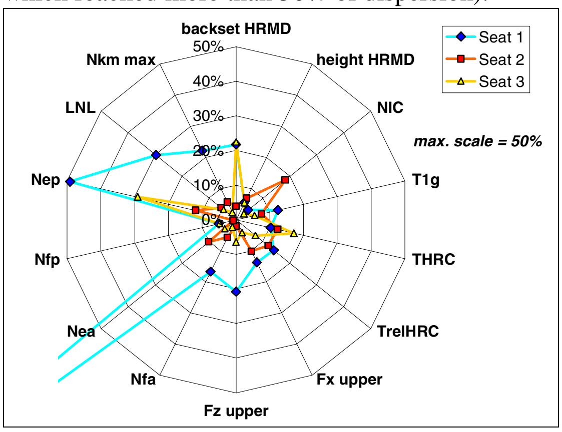

Figure 26. Maximum scattering for repeatability assessment at 16 km/h.

Maximum scattering for reproducibility assessment at 16 km/h

Reproducibility at 16 km/h (see figure 27) shows that scattering is higher than for repeatability but still acceptable (generally between 10 and 40%) for all the parameters except for THRC and Nkm (mainly Nea and Nep which reached more than 50% of dispersion). Fx, Fz and LNL show high scattering for seat 1 only because the values are really low.

Improving training for seat and dummy set-up and defining sled pulse corridor will help to decrease scattering to the level of repeatability.

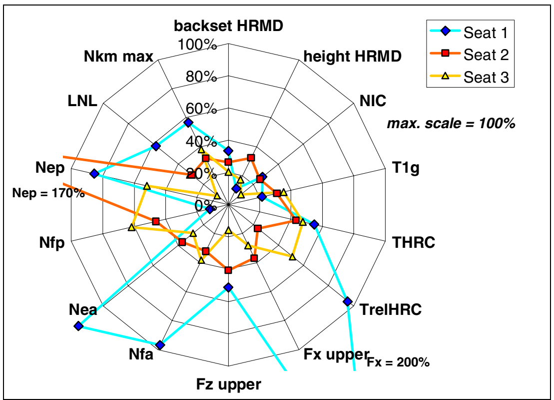

Figure 27. Maximum scattering for reproducibility assessment at 16 km/h.

Maximum scattering for reproducibility assessment at 25 km/h

If we want to do the same comparison for reproducibility at 25 km/h it is needed to enlarge scattering scale. With a maximum scale of 100% we can notice that all the parameters show unacceptable dispersion (generally between 30 and more than 100%) for all the parameters except for backset and height that have no link with impact severity (see figure 28).

It definitively proves that biomechanical criteria cannot be used at this impact severity.

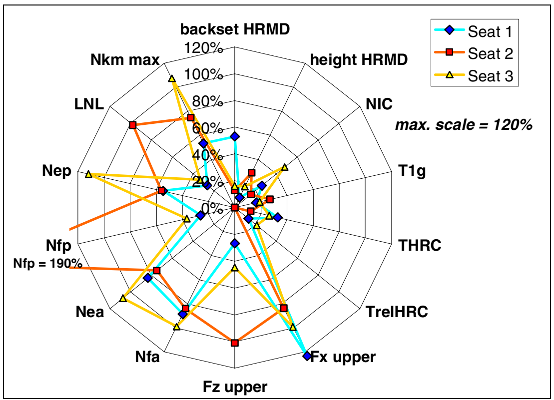

Figure 28. Maximum scattering for reproducibility assessment at 25 km/h.

In conclusion, repeatability (16 km/h) is acceptable, with the exemption of the Nep value (no influence on Nkm max for these tests).

For the delta v 16 km/h tests Nkm (all) and THRC show variations of more than 50%. Forces (Fx/Fz), LNL and T1 are between 20 to 40% variation. NIC showed the lowest variation with values below 30%.

Reproducibility is significantly degraded when delta v 25 km/h pulse is used compared to delta v 16 km/h. In particular the forces and force based criteria show extreme variations (> 100%) with delta v 25 km/h pulse. Result variations clearly question the suitability using these measures at the high severity pulse (delta v 25 km/h).

Combined criteria (« ratings »)

Presentation

When these results were first presented to EuroNCAP, a question was raised : whether the fact to use a combination of several criteria would decrease or not dispersion (like a balance between several criteria dispersion). For this purpose, this paragraph presents dispersion assessed for several ratings inspired by current whiplash rating already published for several years or under construction [1], [2], [3].

As already mentioned earlier in this paper (see Table 2), these ratings are **NOT** proposed by ACEA, they are only based on ratings currently published or under construction.

The philosophy taken to create the ratings is based on the same philosophy as EuroNCAP adult frontal or side score. When a parameter is below the green limit, the maximum score is given. When it is above the red limit, the minimum score is given. When it is between the two limits, a sliding scale is applied.

In order to have a correct scale to compare the results, the sliding scale proposed is between 10 and 0 points. ACEA is not suggesting whiplash score to be 10 points. The reason of choosing 10 points is to get sufficient scale to compare the results.

The method of calculation of the rating is described below:

- each parameter gives a score between 0 and 10 points thanks to the sliding scale.
- the rating is made of 2 to 6 criteria.
- the rating score is the average of 2 to 6 criteria scores.

Therefore:

- a rating score of 10 points means a seat with all the criteria below the green limit
- a rating score of 0 point means a seat with all the criteria above the red limit

We have taken into account three different ratings, named “A”, “B”and “C”. The criteria used for each rating are:

- rating A : NIC, LNL, Nkm
- rating B : NIC, Nkm
- rating C : Fx, Fz, T1g, TrelHRC

A fourth rating has also been used, it combines all the criteria foreseen in the EuroNCAP whiplash WG :

- rating W : NIC, Nkm, Fx, Fz, T1g, TrelHRC

Results

In order to assess consequences on dispersion, the rating has been calculated for all the 16 km/h tests, but also with the average value of each criteria (X_{Tmean} and X_{mean}) and with the extreme values too : maximum value for all the criteria (Max_3 and Max_5), and minimum values for all the criteria (Min_3 and Min_5). This is called respectively “rating with average scores”, “rating with maximum scores”, “rating with minimum scores”.

The three different ratings and the whole one would give homogeneous scores for seat 1 (see figure 29) and different ones for seat 2 (see figure 30) and seat 3 (see figure 31).

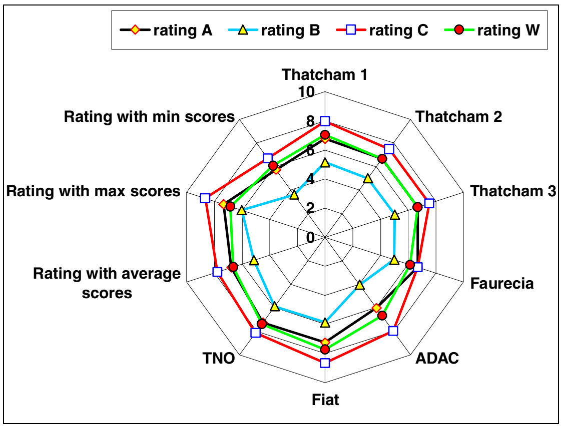

Figure 29. Seat 1 - influence of rating combination on dispersion for 16 km/h whiplash test.

Figure 29 shows that dispersion can lead to 20 % of difference in the rating score for seat 1. Generally extreme scores are close to lab scores. This means all the minimum (or maximum) values appear in the same test.

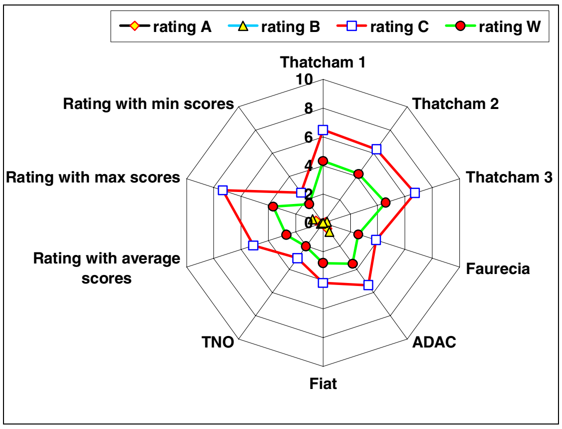

Figure 30. Seat 2 - influence of rating combination on dispersion for 16 km/h whiplash test.

For seat 2, dispersion is important and can bring up to 40 % of difference in the rating score.

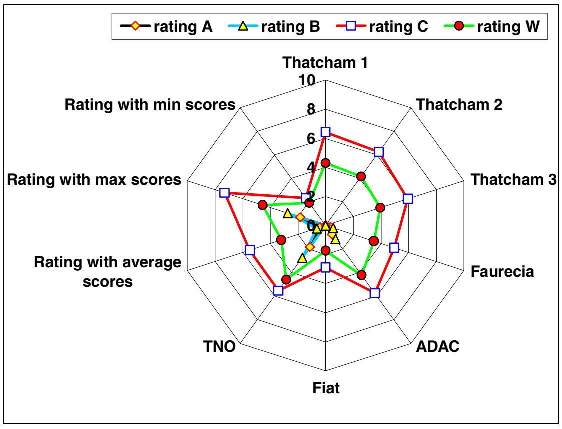

Figure 31. Seat 3 - influence of rating combination on dispersion for 16 km/h whiplash test.

For seat 3, dispersion is important and can bring up to 40 % of difference in the rating score.

Conclusion of rating combinations

In conclusion, no improvement in dispersion occurs when a combination of criteria is used. Therefore, the need is clearly to decrease dispersion by improving reliability of seat and dummy set-up and of pulse reproductibility.

T_{zero} definition

T_{zero} is defined as the first point above 0.5 g measured on the sled accelerometer filtered at CFC 60. The reason why 0.5 g was chosen is because the current definition (1 g) can be in conflict with mechanical systems that are triggered when the acceleration goes above 1g. Moreover 1 g represents 10 % of the maximum value of a 16 km/h test. It was thought to be too high to use as T_{zero} definition.

Whatever the level of T_{zero} (1 g or 0.5 g), it is interesting to notice that defining T_{zero} for an accelerated sled is not so easy because before the beginning of the impact the sled is not at rest (see figure 32) before impact (setting the sled acceleration to 0 before impact could be difficult with such a sled device.

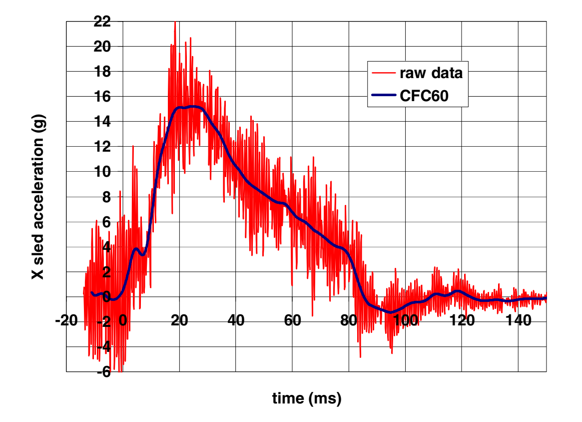

Figure 32. Illustration of possible difficulties to define T_{zero} or accel peak max for a deceleration sled.

What could be added is that it would also be difficult to define any peak in this example (figure 32) where the maximum value is not unique but represented by a plateau.
One of the solutions to improve T_{zero} definition could be to use a specific sensor with a low amplitude range (20 g) in order to define more accurately the 1st point above 0.5g.

CONCLUSION

Initial position

We can sum up the trends by saying that :

- Oscar+HRMD H-point dispersion was within 20 mm for x and 22 mm for z
- BioRID H-point dispersion was within 28 mm for x and 32 mm for z
- BioRID X H-point target with respect to Oscar+HRMD is easily respected but the large band of tolerance is needed since maximum dispersion for X delta H-point was 15 mm
- BioRID Z H-point target with respect to Oscar+HRMD is very difficult to achieve and should be modified (ACEA proposal : same height as for the Oscar + HRMD). Maximum dispersion for Z delta H-point was 18 mm
- HRMD backset dispersion was up to 22 mm
- HRMD height dispersion was up to 26 mm
- BioRID is taller than HRMD (up to 15 mm in the tests performed)
- there is a need to define a BioRID backset for which confidence is enough to help in predicting biomechanical results since current dispersion is 42mm (and 28 mm in height)

Biomechanical criteria

Repeatability tests showed good results of scattering, and reproducibility was acceptable at 16 km/h. Training in seat and dummy set-up will help to improve the results. But the scattering at 25 km/h showed that biomechanical results cannot be used at this impact severity. Indeed, dispersion at 25 km/h was generally between 30 % and more than 100% on biomechanical criteria.
It definitively proves that biomechanical criteria cannot be used at this impact severity.

The three different ratings and the whole one do not show any improvement in dispersion which can lead to 40 % of difference in the rating score. Therefore, in order to improve dispersion one has to put an effort on initial position.

ACEA whiplash subgroup recommendations

Following this extensive analysis, ACEA recommend :

- a clear T_{zero} definition
- a more accurate pulse corridor
- training for seat, HRMD and BioRID set-up
- an update test procedure with pictures to clearly understand the requirements
- an update of Z H-point target for BioRID
- a clearer definition for backset measurement for BioRID to ensure a repeatable position of the BioRID head but also to get a useful parameter for engineers
- clear definition of biomechanical criteria (computer procedure to calculate each criteria)
- no biomechanical criteria at 25 km/h.

ACKNOWLEDGMENTS

ACEA wishes to thank all the labs and all the car manufacturers and seat manufacturers that where involved in this study.

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